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News from the Repair, Evaluation, Maintenance, and Rehabilitation Research Program

Underwater Inspection of Coastal Structures

by Terri Prickett, U.S. Army Engineer Waterways Experiment Station

Most damage to coastal structures, especially rubble-mound breakwaters and jetties, occurs to the submerged portion of the structure. Underwater damage such as that caused by scour, settlement, or scattering and breakage of armor units is not readily visible on the surface. If undetected, it can progress until a major structural collapse occurs. Early detection of structural deterioration is therefore essential for cost-effective management of coastal structures over their lifetimes.

Diver inspections provide some information about the condition of underwater structures, but these surveys are often difficult and risky, hampered by the normal occurrence of waves and currents and limited visibility around the structure. The information obtained from diver surveys is subjective, and spatial detail is sparse. Additionally, results from side-scan sonars, a viable tool for structural surveys (Kucharski and Causner 1990), are semi-quantitative and often sketchy and distorted because of energetic wave and current conditions around the structure.

SeaBat sonar head being deployed

In response to the need for better procedures and equipment for underwater inspections, research was initiated under the REMR Research Program to identify and evaluate hardware and software tools that would produce useful, high-quality results and yet require a minimum level of operator skill, training, and experience. One product developed in the initial investigations was the Coastal Structure Acoustic Raster Scanner (CSARS) system (see *The REMR Bulletin*, Vol. 8, No. 3, 1991). This remote, bottom-deployed system consists of a tripod and a pointable 300-kHz acoustic transducer unit with driving motors and sensors. The tripod is cabled to an operator-controlled shipboard computer system that allows for real-time graphical display and on-site data post-processing. The device has performed successfully in field trials at several coastal sites. A more detailed description of the CSARS system and its development is found in Lott, Howell, and Higley (1990) and Lott (1991).

Since the development of the CSARS system, REMR-based investigations have been directed toward newly emerging high-resolution multibeam sonar systems that have evolved from technological advances on several fronts. These advances include the Differential Global Positioning System (DGPS); advanced computer hardware and software capable of collecting, storing, and processing dense data sets; and improved motion compensators and roll, heave, and pitch sensors. The combination of advanced positioning and motion sensors with new sonar technology has resulted in state-of-the-art optimal swath systems ideally suited for shallow-water survey applications. These commercially available systems have proved superior to the still-prototype CSARS system.

SeaBat head mounted on boat

For this investigation, the SeaBat 9001, developed by RESON, Inc., of Goleta, CA, was selected for testing

above other multibeam systems because it was more compact and less expensive. It is a portable, downward and side-looking single-transducer multibeam sonar system. The main component of the SeaBat is an acoustic sonar head that operates at 455 kHz and transmits 60 sonar beams spaced at 1.5 deg in a fan pattern to provide a maximum sound swath of 90 deg. This configuration enables coverage of twice the water depth. Typically, the sonar head is deployed vertically from a fixed mount off the side of a small vessel and is cabled to an external computer or data logger that controls display, data processing, and output in real time. A pointer device such as a trackball or joystick is used for operational control of the sonar head, which can be tilted for mapping steeply sloped or vertical structures. The SeaBat mounting and beam configuration are illustrated in Figure 1.

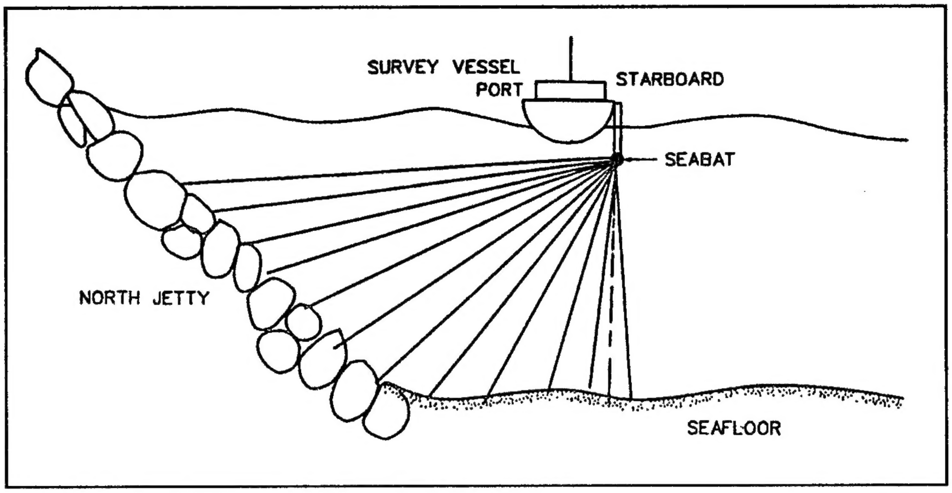

Figure 1. SeaBat mounting and beam configuration on steeply sloping structure (Hughes et al. 1995)

The SeaBat 9001 system can take 60 simultaneous soundings at a rate of more than 15 profiles per second.

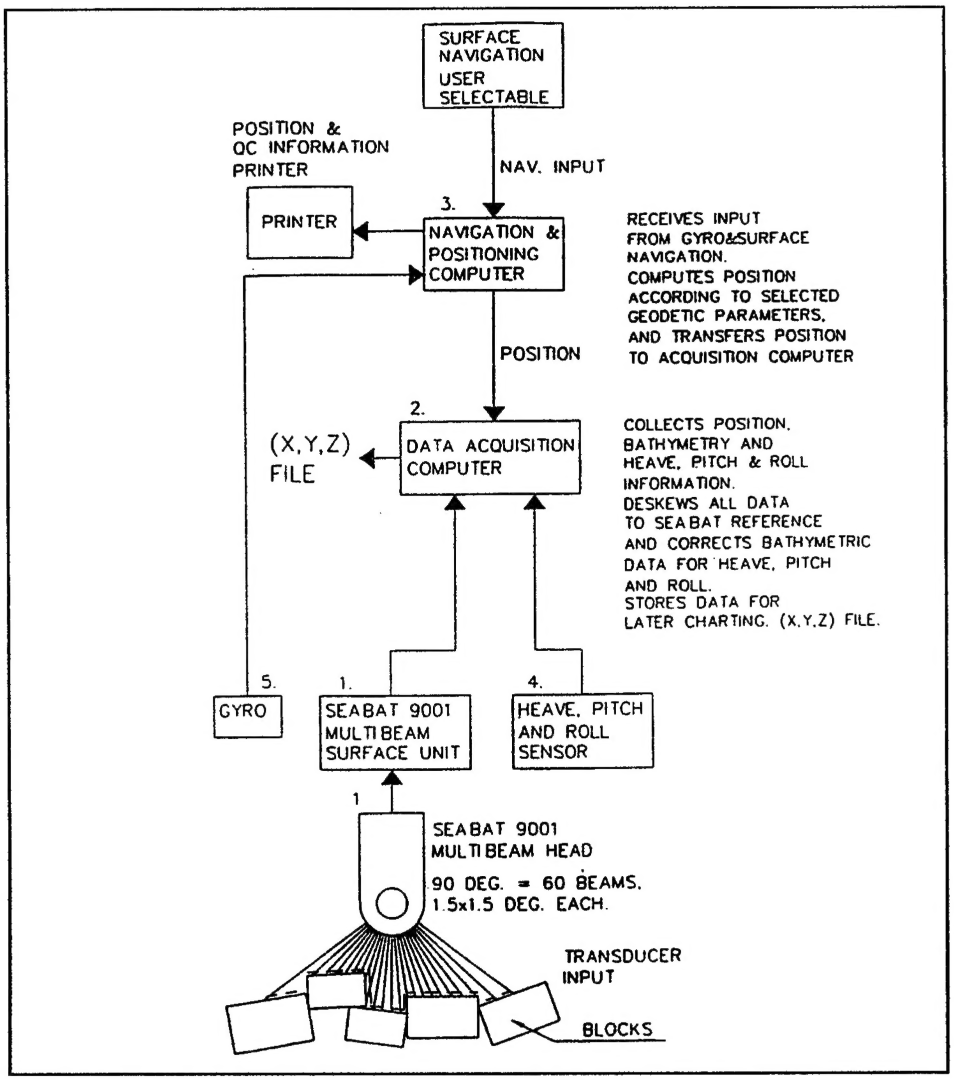

Figure 2. SeaBat system configuration (Headquarters, Department of the Army 1994)

SeaBat depth precision, in ideal conditions, is 0.13 ft (0.04 m) below the sensor and 0.3 ft (0.09 m) at the outermost beams at vessel speeds up to 12 knots (Headquarters, Department of the Army 1994). SeaBat images can be viewed in real time and videotaped for data post-processing quality checks.

In addition to the SeaBat data, simultaneous measurements of vessel position, heading, and motion (heave, pitch, and roll) are required for postprocessing geometric data corrections. Bathymetric data corrections are necessary to produce accurate measurements of true depths referenced to vertical and horizontal datum for individual beams. Computer time tags of all data are also necessary. An overall system configuration is provided in Figure 2.

Once geometrically corrected and processed, the SeaBat provides a dense data set of xyz coordinates of point data (spot) elevations. From this data set, a three-dimensional mesh surface connecting the spot elevations (called digital elevation models (DEMs) or digital terrain models (DTMs)) can be created in addition to specified cross sections and contour maps. A DEM from the Yaquina Bay North Jetty Survey (Hughes et al. 1995) is provided in Figure 3.

SeaBat Field Demonstrations and Trials

In 1993 and 1994, WES investigators disseminated information about the potential uses of the SeaBat system

throughout the hydrographic survey community. As a result, several U.S. Army Corps of Engineers (USACE) Districts and hydrographic survey contractors sponsored SeaBat system demonstrations for varied applications (Table 1). In addition to WES personnel, demonstration attendees included personnel from other USACE Districts, academia, and private hydrographic surveyors.

The Quantitative Imaging work unit of the REMR Research Program also facilitated use of the SeaBat system during 1993 and 1994 for five successful field trials of Corps structural surveys (Table 1). For all of the field trials, the SeaBat system was able to provide valuable, previously unknown information about the underwater condition of the structures.

Development of the SeaBat system and its application to coastal structure surveys continued to evolve as the system was demonstrated and tested. Equipment improvements included innovative mounts and data collection hardware and software. Data collection procedures were tested, data density requirements were explored, and processing techniques were refined.

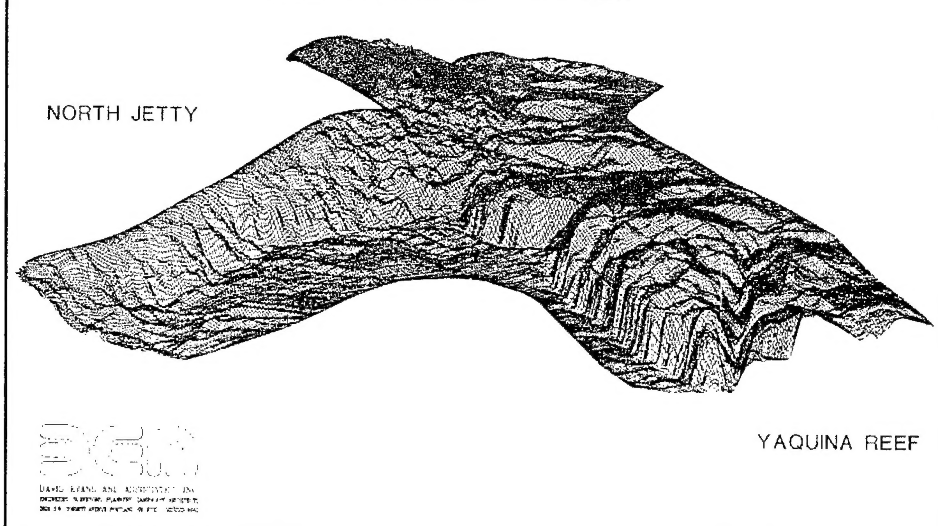

Figure 3. DEM of Yaquina Bay north jetty and Yaquina Reef below-water bathymetry (Hughes et al. 1995)

Summary

The demonstrations and success of the field trials have proved that the commercially available SeaBat multibeam system can be applied for use in coastal structure underwater surveys. Hydrographic surveying using state-of-the-art multibeam swath systems provides nearly 100-percent bathymetric coverage of the structure up to the edge of the water, resulting in a detailed and quantitative definition of the underwater shape of coastal structures. The SeaBat swath systems and others like it are fast becoming standard equipment for shallow-water surveying applications. Several USACE Districts have purchased multibeam systems or are including multibeam sonars in specifications for private survey contractors. Additional details of the SeaBat 9001 and description of other multibeam swath systems employed on USACE hydrographic survey contracts are provided in Engineer Manual 1110-2-1003, "Hydrographic Surveying," (Headquarters, Department of the Army 1994).

For additional information, contact Terri Prickett by calling (601) 634-2337 or e-mailing to *pricket@ex1.wes.army.mil.*

Table 1. SeaBat Demonstrations and Field Trials

Sponsor	Location	Application
Demonstrations		
USACE District, Los Angeles	Los Angeles, CA	San Pedro Breakwater
USACE District Memphis	Memphis, TN	Bridge pier scour on Mississippi River
Oceaneering, Solus Schall Division (Upper Marlboro, MD)	St. Louis, MO	Missouri River Bridge pier scour (after Flood of 1993)
EMC, Inc. (Greenwood, MS)	Crescent City, CA	Harbor entrance survey (dolos inspection)
Ocean Surveys, Inc. (Old Saybrook, CT)	Old Saybrook, CT	Connecticut River entrance on Long Island Sound
WES	Duck, NC	CHL Field Research Facility
Field Trials		
USACE District, Buffalo, and WES	Cleveland, OH	Cuyahoga River retaining structure reconnaissance survey
USACE District, Los Angeles, and WES	Los Angeles, CA	Los Angeles (San Pedro) Harbor and Long Beach breakwaters
USACE District, New York	Long Island, NY	Shinnecock and Moriches Inlets
USACE District, Philadelphia, PA	Rehoboth, DE	Indian River Inlet
WES and USACE District, Portland	Newport, OR	Yaquina Bay north jetty survey

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Terri Prickett *is a physical scientist in the Prototype Measurement and Analysis Branch, Coastal and Hydraulic Laboratory (CHL), U.S. Army Engineer Waterways Experiment Station. Terri joined CHL in 1989 and has been involved with research for various programs pertaining to near- and offshore deployment of both in situ and remote oceanographic sensors (i.e., wave gages and acoustic systems). She received her B.S. degree in Geology at Northeast Louisiana University and is a member of Sigma Xi and the Society of American Military Engineers.*

REMR Research Program Approaches Final Year

September 1998 will mark the completion of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program, but the use of REMR-developed technologies will continue to extend the service life of hydraulic structures long after the program ends (Figures 1-5). On June 3, 1997, the final REMR Field Review Group (FRG) Meeting was held in Washington, D.C. At this time, projects to be finalized by the end of Fiscal Year 1998 were targeted, and some of the outstanding accomplishments of this comprehensive research effort were noted.

Scheduled for completion next year are the following projects:

- Development of management systems for earth and rockfill dams, lift gates, and bridges.
- Guidance on repairs with the use of air-entrained roller-compacted concrete.
- Evaluation of erosion resistance of concrete repair materials.
- Methodology and evaluation procedures for determining the effects of vegetation on levee performance.
- Guidance on repair of leaking joints and cracks in concrete hydraulic structures.
- Development of performance criteria for repair materials for concrete structures and an expert system to aid in the selection of repair materials.
- Development of a universal volative organic compound (VOC) compliant coating system for metal components of locks and dams.
- Guidance for selecting, designing, and building low-cost biotechnical structural erosion control at reservoir shorelines.
- Development of a rock degradation classification system to predict field degradation and optimum use of stone.
- Guidance on innovative, cost-effective methods for rehabilitation of levees.

A World Wide Web (www) home page is under construction for the REMR Materials Database System (MDBS), which aids in the selection of methods and materials for the repair of concrete, and should be on-line later this year. To date, the MDBS contains information about 1,879 commercial products, Corps of Engineers' tests results for 219 products, and test results from non-Corps sources for 115 other products. The database is expanded by soliciting input from manufacturers, Corps laboratories, and other agencies. Maintenance and expansion of the MDBS will be continued after the REMR Research Program ends next year. Planned upgrades to the system will make it more accessible to field personnel as well as more user friendly. An expert system for selecting methods and materials for the repair of concrete is under development and will tie into the MDBS.

Currently, 159 REMR technical reports have been printed, and 19 more are scheduled for publication in the upcoming year. *The REMR Notebook*, which contains over 300 technical notes and materials data sheets, will be available next year on CD-ROM, with hyperlinked text that will aid the user in moving from one area to another.

Some of the recent program accomplishments reported at the meeting include development of:

- Apparatus for evaluation of materials to minimize moisture intrusion into brick and masonry structures.
- A procedure for underwater installation of geomembrane repair systems for dam rehabilitation (*The REMR Bulletin*, Vol. 14, No. 1, February 1997, available on the Internet at *http://www.wes.army.mil/REMR/remr.html*).
- A non-linear, ultrasonic pulse-echo system for nondestructive testing of concrete to depths up to ten times that of the 1- to 2-ft depths available in current systems.

- Procedures for the selection of repair materials for hydraulic steel structures.
- Improved stability criteria for concrete gravity structures (Figure 1) (*The REMR Bulletin*, Vol. 13, No. 1, February 1996, available on the Internet).

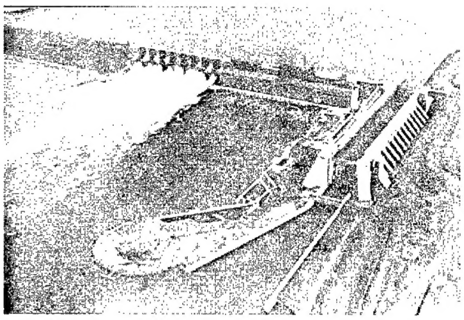


Figure 1. Improved stability criteria for gravity structures were used to assess the stability of Little Goose Lock and Dam, WA

Among the noteworthy past accomplishments that can be credited to the REMR Research Program are the use of a blended chemical high temperature process (BCHT) for cleaning relief wells (Figure 2) (see *The REMR Bulletin*, Vol. 10, No. 3, September 1993); the invention of a patented concrete armor unit, CORE-LOC™, for rehabilitation of coastal breakwaters and jetties (Figure 3) (*The REMR Bulletin*, Vol. 12, No. 1, January 1995, available on the Internet); and the development of a precast concrete stay-in-place forming system for repair of lock walls (Figure 4) (*The REMR Bulletin*, Vol. 10, No. 2, June 1993; and Vol. 12, No. 3, October 1995, available on the Internet).

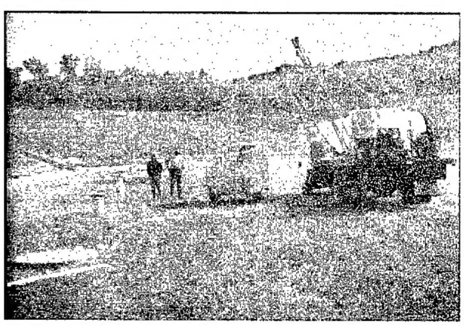


Figure 2. The blended chemical high-temperature treatment process was used to clean wells at Brooksville Dam, IN

Other program achievements include the development of:

- A new design for navigation lock lift-gates) (Figure 5).

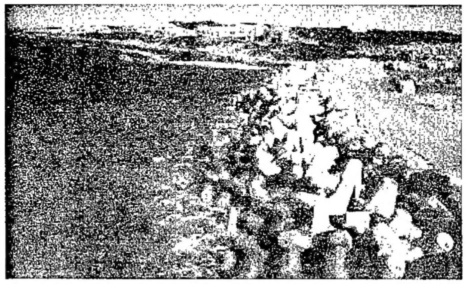


Figure 3. CORE-LOC units were used to provide protection for a breakwater and peninsula at Port St. Francis in South Africa

- Guidelines for maintenance of hydraulic structures containing lead-pigmented paints (*The REMR Bulletin*, Vol. 9, No. 2, June 1992; Vol. 11, No. 1, April 1994).
- HIVELD2, a personal computer-based, numerical model that can be used in the field for evaluation and maintenance of high-velocity channels (*The REMR Bulletin*, Vol. 9, No. 4, December 1992).
- STREMR, a numerical model for evaluation of near-field turbulent flow conditions (*The REMR Bulletin*, Vol. 11, No. 2, July 1994).
- Techniques for eliminating or preventing icing of components of lock and dam machinery (*The REMR Bulletin*, Vol. 9, No. 4, December 1992; Vol. 10, No. 4, December 1993; Vol. 11, No. 1, April 1994; Vol. 12, No. 2, May 1995, available on the Internet).
- A procedure for determining the erosion potential of an emergency spillway along with preventative measures for protecting emergency spillways with high erosion potential (*The REMR Bulletin*, Vol. 1, No. 3, July 1984; Vol. 5, No. 1, March 1988; Vol. 9, No. 1, March 1992).

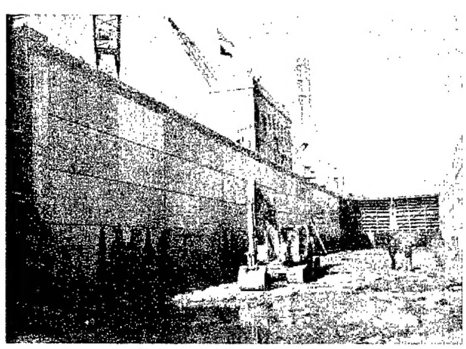


Figure 4. Allegheny River Lock and Dam No. 4 was rehabilitated with precast concrete stay-in-place panels.

- Maintenance management systems for tainter and roller gates, miter and sector lock gates, lock filling and emptying valves, lock and dam retaining structures, and riverine stone training dike and revetments (*The REMR Bulletin*, Vol. 9, No. 1, March 1992).
- A method for evaluation of environmentally acceptable greases and oils for use on hydraulic structures and in hydraulic units (*The REMR Bulletin*, Vol. 9, No. 3, September 1992).

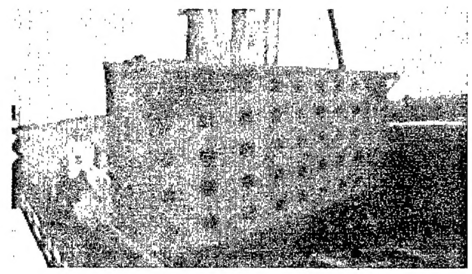


Figure 5. A REMR study on gate failures from metal fatigue provided input for the design of fatigue-resistant navigation lock lift gates at Lock and Dam No. 27

Initially, REMR technology transfer relied on traditional media such as technical reports, bulletins, videos, and fact sheets. More recent efforts have moved into other electronic arenas, including the Internet. The REMR Web Site (located at *http://www.wes.army.mil/REMR/remr.html*) provides updated listings of REMR technical reports; technical notes, and material data sheets; a search engine for REMR publications; e-mail links to experts in each of the REMR research areas; and the latest issues of *The REMR Bulletin.* Of the 48 issues of *The REMR Bulletin,* the last six are available on the REMR Home Page.

The continued safe and efficient operation and maintenance of Corps projects are essential to the economic well-being of the country. The cost associated with the evaluation, maintenance, repair, and rehabilitation of Corps projects has become a major part of the Corps' budget. The REMR Research Program has helped to ensure that the Corps gets the maximum value for the dollars expended by identifying and developing cost-effective technologies.

For additional information, contact Lee Byrne, REMR Technology Transfer Specialist by calling 601-634-2587 or by e-mailing to *byrnel@mail.wes.army.mil.*

Effectiveness of Selected Grout Systems for Embedment of Anchors Into Hardened Concrete Under Wet and Dry Conditions

by Willie E. McDonald, U.S. Army Engineer Waterways Experiment Station

Rehabilitation procedures for hydraulic concrete structures frequently call for the removal and replacement of defective concrete. The new concrete is then attached to the existing structure by means of steel reinforcing anchors embedded into the base concrete. In a typical installation, a small-diameter hole is drilled into the sound concrete and cleaned. Then a capsule containing either polyester or vinylester resin is inserted into the hole, and the anchor is spun into the hole. While this technique is normally satisfactory under dry conditions, a high incidence of anchor failure is reported when installation occurs under submerged conditions. Consequently, a study was initiated as part of the REMR Research Program to evaluate the effectiveness of selected grout systems for embedment of anchors in concrete under dry and submerged conditions.

Two epoxies, a vinylester, and a cementitious grout, were selected for evaluation. Three anchors (No. 6 reinforcing bars) were installed for each experimental condition. Pullout analyses were conducted at 1, 3, 7, 28, and 265 days following anchor installation. Creep analyses were initiated at 7-days age by subjecting pullout specimens to a sustained load of 60 percent of the anchor yield strength. Anchor slippage at the end of the specimen opposite the loaded end was measured periodically during the 6-month loading period.

Specimens

Twelve concrete blocks were fabricated and represented the base concrete for anchor installations. Recesses on the top surfaces of six of these concrete blocks allowed the water to pond and thereby simulate submerged conditions (Figures 1 and 2). Twelve holes were predrilled into each concrete block with an impact hammer drill and carbide-tip bits for installation of the anchors. The diameters and depths of the holes were drilled in accordance with recommended manufacturers' specifications for each respective adhesive product. Twenty-four 152- by 152- by 457-mm concrete beams were fabricated to represent the base concrete for anchor installations in creep analyses. One percussion hole was predrilled into each concrete beam according to specifications. The mixture proportions for the fabricated blocks and beams consisted of a conventional 20.7-MPa concrete. Anchor specimens consisted of No. 6 (19-mm-diam) A36 reinforcement steel bars.

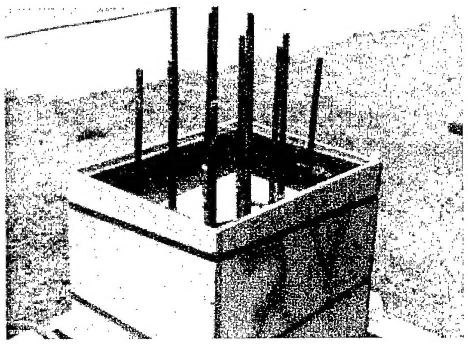


Figure 1. Typical fabricated concrete blocks for dry anchor installations

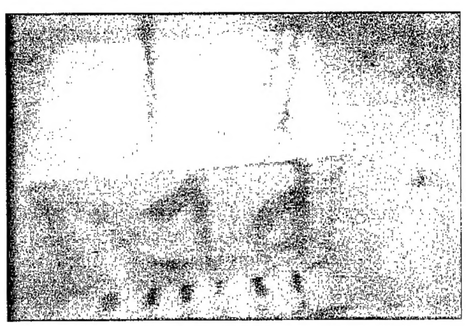


Figure 2. Typical fabricated concrete blocks for submerged anchor installations

Adhesive Products and Anchor Installations

For the pullout analyses, 144 anchor specimens were installed, and for the creep analyses, 24 anchors were installed. For both pullout and creep analyses, half of the anchors were installed in dry conditions, and half were installed in submerged conditions. Prior to dry and wet installations of the anchors, the predrilled holes were air blown and cleaned with a nylon brush to rid them of dust and loose particles. For submerged anchor installations, water was ponded for 2 weeks prior to anchor installations to saturate the holes. The adhesive products used in this study were designated as Adhesive A, Adhesive B, Adhesive C, Adhesive D, and Adhesive E.

Adhesive A was a two-component ceramic-filled epoxy adhesive. The product was contained in a two-chambered cartridge consisting of epoxy and hardener components in separate chambers. The components were blended by static mixer elements contained within a nozzle system. The product was light gray when dispensed with a hand-operated caulking gun. Anchors installed with Adhesive A were embedded in 22-mm-diam holes to a depth of 171 mm for dry and submerged installations. The holes were filled to one-half the hole depth by inserting the dispenser nozzle to the bottom of the hole and slowly withdrawing the nozzle. The anchors were immediately inserted and slowly pushed to the bottom of the holes with a clockwise/counterclockwise rotational motion, displacing the adhesive to the top of the hole.

Adhesive B was a light-paste epoxy adhesive filled with superfine aggregates and hardener components. The proportioned components, which were concrete gray and contained in coaxial cartridges, were blended in a static mixing nozzle and dispensed with a pneumatic dispenser. Anchors installed with Adhesive B were embedded in 22-mm-diam holes at depths of 222 and 279 mm, respectively, for dry and submerged installations. Following the manufacturer's recommendation, Adhesive B was heated to 267° C prior to anchor installations to compensate for the anticipated reduction in set time under submerged conditions. (Apparently, heating the adhesive speeds

up the reaction process.) Procedures for cleaning of holes and anchor installations with Adhesive B were the same as described for Adhesive A.

Adhesive C represented the combined application of two vinylester resins for anchor installations. The first was a multi-component vinylester resin contained in a 19- by 168-mm dual glass vial capsule and consisted of quartz sand, a benzol peroxide hardening agent, and vinylester resin. The second was a two-component vinylester resin packaged in a two-chambered plastic cartridge with the polyester/silica resin and dibenzol peroxide hardener components in separate chambers. The components were blended by static mixer elements with a nozzle attachment and dispensed with a hand-operated caulking gun. Following the previously described hole-cleaning procedures, anchor specimens installed with Adhesive C were embedded in percussion holes 25.4 mm in diameter and 168 mm in depth for both dry and submerged installations. The two-component resin was dispensed to about half of the hole depth followed by insertion of the multi-component resin capsule, which displaced the two-component resin to the top of the hole. An electric drill with an anchor-setting attachment was used to spin the anchors into the hole. This process resulted in both breaking the multi-component glass capsule and mixing the resin components.

The combined use of the multi- and two-component capsules affords an advantage for submerged installations not available with applications of the multi-component adhesive alone. When the multi-component adhesive is used alone, water becomes trapped between the walls of the capsule and the hole, mixes with the multi-component resin, and weakens the bonding capacity. However, the two-component resin displaces the trapped water and ensures better bonding. Application of Adhesive C for submerged anchors is described in McDonald (1989).

Adhesive D was the same multi-component vinylester resin described previously. As a result of the manufacturer's recommendation against the use of this resin alone for submerged applications, it was included only for dry anchor installations. Anchor specimens installed using Adhesive D were embedded in 22-mm-diam and 168-mm-deep drilled holes. Again, procedures for cleaning the holes and installing the anchors with Adhesive D followed those described for Adhesive A.

Adhesive E, manufactured specifically for underwater anchor installations, was a cementitious compound encased in a special plastic wrapping which, when submerged, allowed controlled wetting of the contents to form a thixotropic grout. The adhesive was packaged in cellophane-type, sausage-shaped cartridges designed for insertion into a range of hole sizes. Following normal hole-cleaning procedures, the cartridge was submerged in water for 300 to 900 sec. The cartridges were inserted into 25.4-mm-diam and 305-mm-deep drilled holes. The anchor specimens were forced into the holes through the cartridges and rotated to initiate the chemical bonding process. Reaction of the components occurred when the cartridge was ruptured by insertion of the anchor.

Equipment and Procedures

Pullout analysis loads were applied by a hollow-core hydraulic ram with hydraulic pressure supplied by an electrically powered pump. The loading system was calibrated by the correlation of voltage outputs (measured by a voltage meter) and loads obtained from a 3,000-MPa universal laboratory machine. Digital display of the voltage output allowed the magnitude and rate of loading to be monitored as well as measured with the voltage meter throughout the investigation. The hydraulic ram was centered over the anchor specimens and secured by a head and jaw grip assemble. The head and jaw assemble also provided load transfer from the hydraulic ram to the anchor specimens during evaluation. A linear variable differential transformer gage was placed on the top surface of the exposed end of the anchor specimens to measure displacements of the anchors relative to the surface of the concrete blocks. Continuous measurements of load and displacements throughout the evaluation procedure were processed and recorded by means of an electronic data acquisition/control unit configured in the overall system. The loading rate for all pullout analyses was maintained at approximately 0.34 MPa per second.

Long-term creep strain analysis loads were also applied by a calibrated hydraulic ram and supply pump setup similar to the setup used for pullout analyses without the data acquisition/control unit. The lower ends of the concrete beams were saw cut at depths specified for anchor embedments to expose the ends of the anchors opposite the loaded ends. This procedure allowed anchor displacements to be measured by positioning a mechanical dial gage extensometer on the top of the exposed surface of the anchors. The anchor specimens were loaded 7 days after embedment under a sustained load of 60 percent of the yield strength of the anchors. Slip deflections were measured periodically during the 6-month period.

Pullout Analyses

Results of pullout analyses on dry and submerged anchor installations bonded by the representative adhesive products correspond with 1-, 3-, 7-, 28-days and 1-year maturity ages for evaluation of anchors following installations. The basis for comparisons of anchor performances is given by tensile load capacities as pullout loads at 2.54- and 5.08-mm displacements and also maximum loads (McDonald 1990).

Adhesive A (epoxy)

For dry anchor installations bonded by Adhesive A, the maximum average tensile load capacities attained were approximately equal to the ultimate strength of the anchors (290 MPa) with the exception of early age, 1-day anchors. Here, the average tensile capacity attained was about half the ultimate anchor strength. However, in pullout analyses for submerged anchor installations, very poor performances were characterized by erratic, inconsistent, and low tensile load capacities. By comparison, very significant differences were typical for performances of dry-versus-submerged installations with substantially lower tensile load capacities for the submerged installations. Dry anchor installations attained an average of 2.5 to 8 times greater tensile capacities than submerged installations. Dry-versus-submerged anchor performances at displacement of 5.08 mm are shown in Figure 3.

Since these results differed significantly from the manufacturer's specifications, a

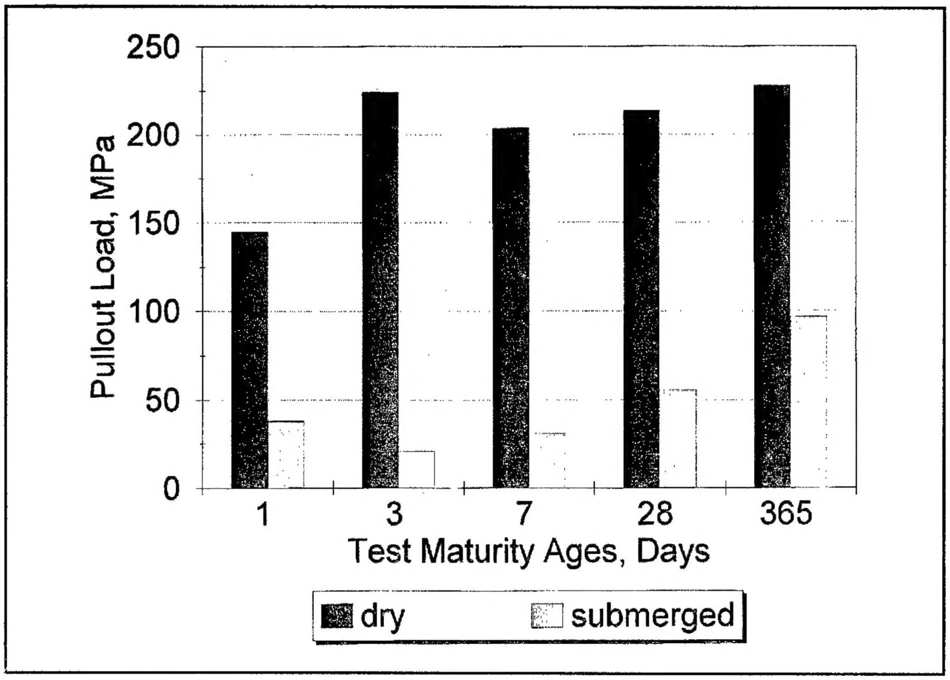


Figure 3. Average tensile capacity at 5.08-cm displacements of anchors installed with Adhesive A under dry and submerged conditions

representative for the manufacturer of Adhesive A was consulted and consequently agreed to provide an onsite review of laboratory procedures for bonding submerged anchor installations. Only minor deviations from the recommended procedures were noted. Additional submerged anchor installations carefully incorporated the minor procedural changes, and subsequent experiments were conducted. Although slightly improved results were obtained, the criteria for 2 weeks of saturation for the holes were not maintained. To determine the effects of hole saturation on the bond properties of Adhesive A, submerged anchors were installed and 3-day analyses conducted after 3, 7, and 14 days of hole saturations.

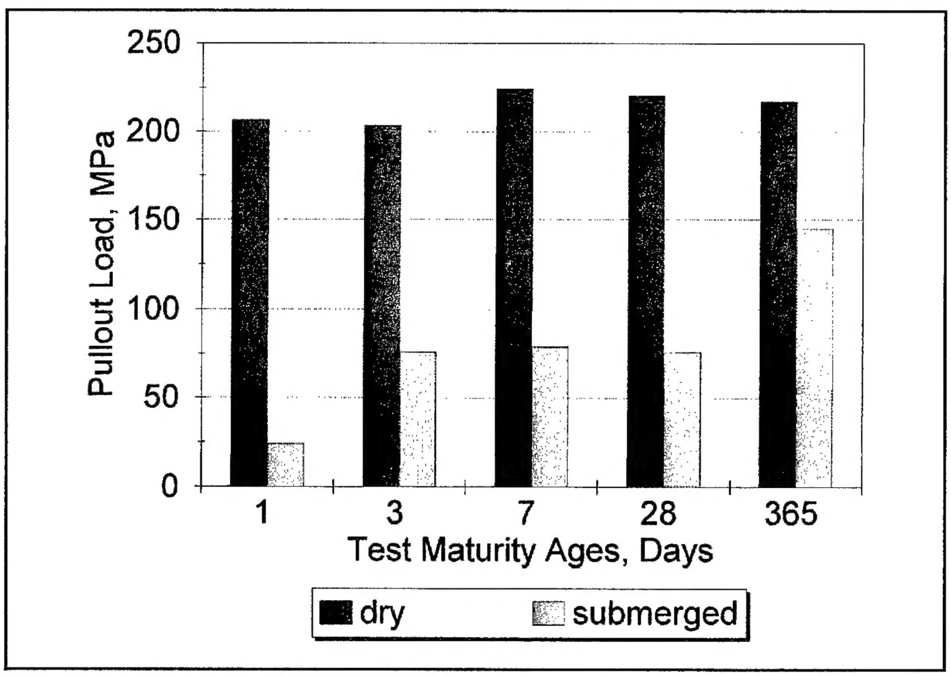


Figure 4. Average tensile capacity at 5.08-cm displacements of anchors installed with Adhesive B under dry and submerged conditions

The results of the pullout analyses for different saturation periods were inconclusive. No definite correlation was indicated between the 3, 7, and 14 days of saturation and the resulting bonding capacity provided by Adhesive A. However, the pattern of erratic and poor performances for submerged anchor installations continued to be demonstrated for each saturation period. These results served to confirm previous investigations in which Adhesive A failed to provide adequate bonding capacities for anchor installations under submerged conditions.

Adhesive B (epoxy)

Pullout analyses conducted on anchors bonded by Adhesive B followed similar patterns as with Adhesive A. Dry installations exhibited tensile capacities within a range approximately that of the ultimate strength of the anchors with the early age, 1-day anchors, in this case attaining average tensile capacity about 33 percent less than the ultimate anchor strength. Anchor performances for submerged installations were again characterized by inconsistently poor performances of 1.5 to 4 times less tensile capacities than for dry installations. Comparison of dry-versus-submerged anchor performances at 5.08-mm displacements for Adhesive B are illustrated in Figure 4.

Review of anchor failures for submerged installations with Adhesives A and B indicated a lack of effective bonding between the adhesives and the inner walls of the holes. This is supported by observations that the adhesives remained physically smooth and intact after failure at the interfaces with the inner walls of the holes. Normally, some fracture of material would be expected as the bonds are broken during failure.

Adhesive C (composite vinylester)

For Adhesive C, anchor performances for dry installations averaged maximum sustained tensile load capacities greater than the ultimate strength of the anchors in each of the experiments. However, distinct reductions were exhibited for submerged installations averaging slightly more than 1.5 times lower tensile capacities. Average pullout loads for dry-versus-submerged installations at

5.08-mm anchor displacements are shown in Figure 5.

Adhesive D (vinylester)

Adhesive D was used only for bonding dry installation of anchors. Maximum tensile capacities sustained by these averaged slightly lower than the ultimate anchor strength. Significantly lower tensile capacities given for long-term evaluations (1 year) on these anchors are attributed to edge failures within the concrete block. Anchor performances at 2.54- and 5.08-mm displacements consistently averaged sustained tensile capacities greater than the yield strength of the anchors.

Adhesive E (cementitious)

Pullout analysis results for applications of Adhesive E in submerged installations indicated consistent performances by these anchors throughout all experiments, with the exception of long-term (1-year) evaluations. During storage of the concrete block containing the 1-year anchor installations, inadvertent leakage of ponded water exposed the anchors to periods of dry conditions (several days). The dry conditions are believed to have disrupted the hydration process of the cementitious adhesive and thus cause reductions in the tensile capacities as indicated. The average maximum tensile capacities were within the range of the ultimate anchor strength (except for about a 20-percent reduction in 3- and 7-day analyses). Average tensile capacities at 2.54- and 5.08-mm displacements were equal to or greater than the yield strength of the anchors.

Creep Analyses

The basis for comparisons of anchor performances is considered by anchor slippage, which is depicted by plots of measured displacements versus time. After 6 months of sustained loading, anchor performances in creep analyses followed a similar trend as in pullout analyses. For Adhesives A, dry installations exhibited low average slippage of 0.013 mm while submerged installations exhibited 76 times higher average slippage of 0.965 mm (average of two anchor specimens). Average slippage exhibited by dry installations with Adhesive B was 0.831 cm while submerged installations failed during application of creep loading.

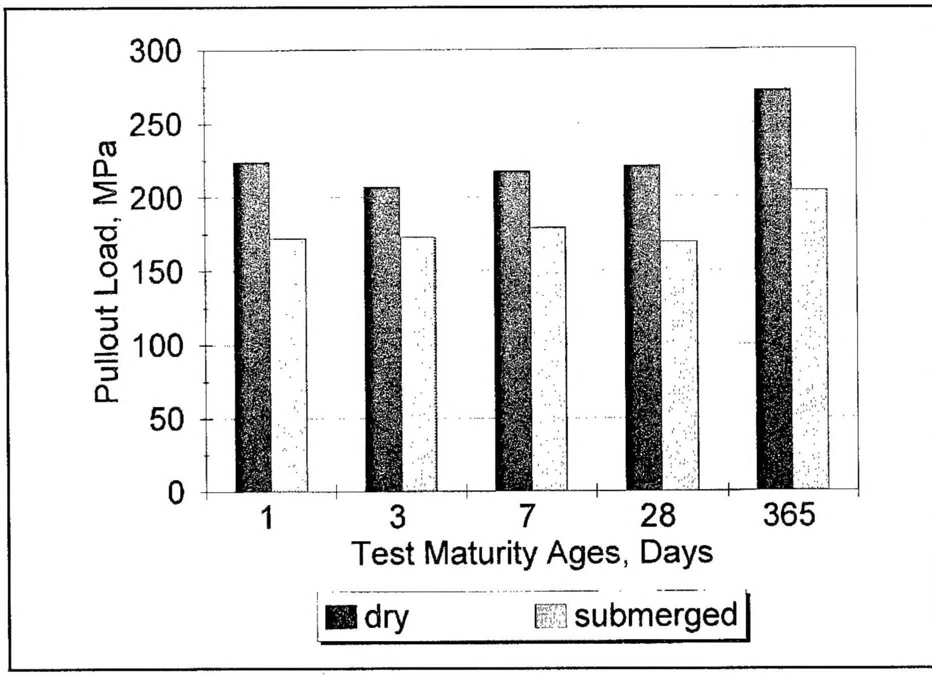


Figure 5. Average tensile capacity at 5.08-mm displacements of anchors installed with Adhesive C under dry and submerged conditions

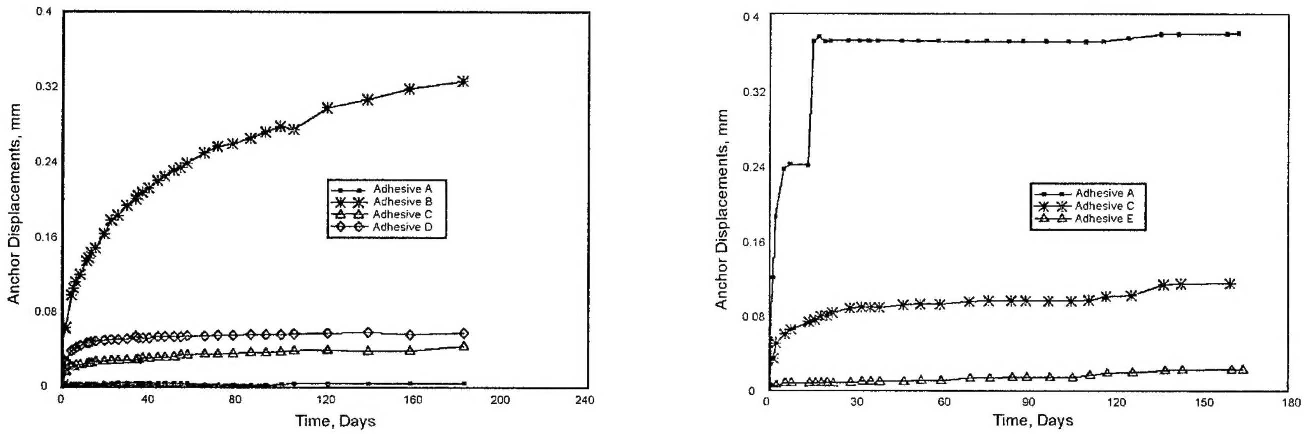
For Adhesive C, averaged slippages for dry and submerged installations were 0.114 and 0.295 cm, respectively. Slippage for submerged installations was approximately 2.5 times higher than for dry installations. Both Adhesive D (dry installations) and Adhesive E (submerged installations) had low average slippages of 0.149 and 0.061 mm, respectively.

Conclusion

In general, adhesive performance in pullout analyses essentially followed a similar pattern as shown in previous studies (McDonald 1990). Satisfactory results were obtained for anchor installation under dry conditions for applications using each adhesive product. However, obvious reductions in tensile loading capacities were evident for anchor installations under submerged conditions. The best results achieved for anchor installations under submerged conditions were provided by Adhesives C and E, respectively. Apparently, water remaining in the holes following insertion of Adhesives A and B significantly affected the capabilities of these adhesives to sufficiently bond anchor installations under submerged conditions. This was indicated by the mode of failure in pullout analyses in which there was no evidence of physical bonding at the interface of the adhesives and the inner walls of the drilled holes.

Results for adhesive performance in creep analyses for dry anchor installations indicated that, with the exception of Adhesive B, each anchor provided satisfactory resistance to anchor slippage (Figure 6). Similar to patterns established in pullout analysis performances, significant reductions in performances by the adhesives were also seen in creep analyses conducted for submerged anchor installations. Likewise, Adhesives C and E showed acceptable performances for submerged applications. By comparison, the creep analysis results also confirmed previous creep analysis studies (Best and McDonald 1990), the exception here being inconsistent performances in submerged creep analyses by the representative epoxy adhesives.

From overall comparisons of pullout and creep analysis results, Adhesives A and B (representative epoxy products) failed to exhibit capabilities for providing acceptable bonding of anchor installations under submerged conditions. Therefore, Adhesives C or E should be used for such applications. For dry anchor installations, maximum design loads should not exceed the tensile loading capacity of the selected adhesive corresponding to analysis results for 2.54-mm anchor displacements.



a. Dry **b. Wet**

Figure 6. Results of creep tests for dry and submerged anchor installations

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"REMR Management Systems — Navigation Structures, Condition Rating Procedures for Tainter Dam and Lock Gates," by Lowell Greimann, James Stecker, and Mike Nop, Technical Report REMR-OM-17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1995. AD-A303 294

Useful Reference on Liquefaction Remediation Published

An informative reference for engineers and researchers involved in liquefaction remediation is the recently published English version of the *Handbook on Liquefaction Remediation of Reclaimed Land*. Originally written in Japanese and published in 1993 by the Coastal Development Institute of Technology, Japan, the handbook presents principles and techniques that are applicable to all regions that are seismically active. It describes methods for liquefaction remediation of reclaimed land based on 30 years of research and experience in the design and construction of port facilities in Japan. This translation is the result of a collaborative effort between the U.S. Army Engineer Waterways Experiment Station (WES) and the Port and Harbour Research Institute of Japan. The WES effort was funded under the REMR and the Earthquake Engineering Research Programs. For information on obtaining a copy of the handbook, write to A.A. Balkema Publishers, Old Post Road, Brookfield, VT 05036-9704. Library copies are available on an interlibrary loan service to Federal and State agencies, scientific and educational institutions, and established engineering or industrial firms. Write to Director, USAE Waterways Experiment Station, ATTN: WESIM-MI-R, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601)634-2571; or Fax (601) 634-2542.

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